Geol. Lib.
TN
948
M7K6

Kithil

Monazite, Thorium and
Mesothorium

(4)

THE LIBRARY
OF
THE UNIVERSITY
OF CALIFORNIA
LOS ANGELES

The RALPH D. [illegible] LIBRARY
DEPARTMENT OF GEOLOGY
UNIVERSITY of CALIFORNIA
LOS ANGELES, CALIF.

catos sep-FJA
U. C. L. A. DUPLICATE

Technical Paper 110 Mineral Technology 8

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

MONAZITE, THORIUM, AND MESOTHORIUM

BY

KARL L. KITHIL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

The Bureau of Mines, in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications.

When this edition is exhausted copies may be obtained at cost price only through the superintendent of documents, Government Printing Office, Washington, D. C.

The superintendent of documents *is not an official of the Bureau of Mines.* His is an entirely separate office and he should be addressed:

SUPERINTENDENT OF DOCUMENTS,
Government Printing Office,
Washington, D. C.

The general law under which publications are distributed prohibits the giving of more than one copy of a publication to one person. The cost of this publication is 5 cents.

First edition. June, 1915.

Geology
Library
TN 948
M7K6

CONTENTS.

	Page.
Introduction	5
Properties of monazite	5
Occurrence of monazite	6
Where monazite is mined	6
History of production of monazite	7
First German thorium convention	7
Second German thorium convention	8
Causes of reduced price of thorium	9
Consumption of monazite	9
Prospecting for monazite deposits	10
Use of spectroscope	10
Monazite deposits in North and South Carolina	10
North Carolina	11
South Carolina	12
Deposits in Idaho and Colorado	12
Idaho	12
Colorado	13
Deposits in Brazil	13
Mining of monazite in the Carolinas	14
Milling methods in the Carolinas	16
Electromagnetic equipment used	16
By-product separation	17
Cost of mining and milling	17
Comments on electromagnetic process	18
Estimated monazite resources	19
Duty on monazite exported from United States and Brazil	20
United States	20
Brazil	20
Import duties on monazite	20
Examination and valuation of monazite deposits	20
Attempts to use by-products	22
Method for the determination of thorium in monazite	23
Treatment of monazite for the extraction of thorium	24
Separation of mesothorium on a commercial scale	25
Quantitative determination of mesothorium	26
Minerals in monazite sands	27
Flow sheet	29
Selected bibliography	30
Publications on mineral technology	31

ILLUSTRATION.

FIGURE 1. Flow sheet, showing steps in process of magnetic separation of monazite sands 29

MONAZITE, THORIUM, AND MESOTHORIUM.

By Karl L. Kithil.

INTRODUCTION.

The monazite industry in the United States has been practically at a standstill since 1906, principally for the reason that monazite could be mined and obtained cheaper from Brazil, where large deposits are found and exploited along the seacoast and in the interior. Formerly part of the monazite mined in the States of North and South Carolina was used for the manufacture of thorium nitrate in this country and part of the production was sent to Germany. It seems an opportune time to call attention to the monazite deposits in the United States, as the imports of thorium nitrate are at present curtailed. There is reason to believe that a more general manufacture of thorium nitrate may be developed in this country. It may be many years before supplies of the nitrate from Europe can be depended upon.

There are deposits of monazite in several of our States, and with the knowledge that a valuable product—mesothorium—can be made as a by-product from the residues of thorium nitrate manufacture the industry may be developed in this country and should pay well. Mesothorium is used successfully in therapy in the same manner as radium.

With these facts in view the following description of the occurrences of monazite in the United States, the uses to which its products can be put, and the methods of mining and treatment has been prepared by the Bureau of Mines with the purpose of aiding more efficient utilization of radioactive minerals.

PROPERTIES OF MONAZITE.

Monazite is an anhydrous phosphate of the rare earths, especially cerium, lanthanum, neodymium, praseodymium, yttrium, and erbium, and contains also a small percentage of thorium. So far its content of thoria only gives the mineral its commercial importance, although a market is being developed for some of the other rare earths in special types of electrodes for arc lamps and in the flaming arc. The content of thoria in monazite is small and varies from a fraction of 1 per cent to about 12 per cent, although monazite containing less than $3\frac{1}{2}$ per cent of ThO_2 can not be used successfully in

1019019

the manufacture of thorium nitrate, which is the important chemical product necessary for the manufacture of incandescent gas mantles. In this manufacture the thorium is mixed with 1 to 2 per cent of other nitrates of the rare earths. References to the percentage of thoria in "monazite" generally apply to a sand containing about 92 to 95 per cent of true monazite; such sand is sold in the market on the basis of its content of thoria at a fixed price per unit.

Monazite possesses radioactive properties strong enough to affect a photographic plate and to be measured in the electroscope. The activity of the sand is due to its content of mesothorium and radium.

The specific gravity of monazite varies from 4.9 to 5.3. It has a hardness of 5, is somewhat brittle, and can be easily pulverized.

Nearly all of the monazite brought to the market is of a yellowish, resinous color. The Brazilian monazite of the coast lands appears to have a more uniform shade of color and size of grain than the monazite from the interior. The region from which monazite from the Carolinas has been mined can often be determined by its color alone. Carolinian monazite ranges from yellowish to brownish, greenish and grayish in color.

OCCURRENCE OF MONAZITE.

Monazite is usually found in the gravel of small streams or bottom lands, but sometimes it is also found in the soil of hillsides. In Brazil it occurs also in the beach sands of the coast. In places it is found in small crystals in gneiss, granite, and pegmatite (crystalline) rocks.

As these rocks become disintegrated, the crystals are washed into the creeks and streams and, together with other heavy sands, are deposited in the beds of such watercourses. They are thus concentrated in the gravel by the natural flow of the water; the lighter clay and quartz sand being carried away. On the coast of Brazil the monazite from the crystalline rocks of the coastal mountains is concentrated in strata by the waves of the sea. The mountain sides are washed down by the strong waves at high tide and during storms.

In some places, especially Norway, monazite is imbedded in thin layers of mica (biotite) in strata or, in places, in mica schists. Such monazite is usually of high grade but, on account of the enormous masses of rock material that have to be handled and crushed before concentration, these deposits can not be considered of commercial importance. The proportion of monazite in these rocks averages perhaps 0.01 per cent.

WHERE MONAZITE IS MINED.

Monazite has thus far been mined successfully only in North and South America—in North America, in the Carolinas and in Idaho, and in South America in Brazil. The Brazil deposits occur along the coast of the States of Bahia and Espirito Santo, and also less

abundantly on the Parahyba River in the States of Rio de Janeiro and Minas Geraes. Other coastal lands in the State of Rio de Janeiro have also been worked. Deposits of monazite sand have been found, too, in Swaziland, Africa, as well as in Ceylon and in Australia. In Jekaterinburg, Russia, it occurs in native rock and placers. It has also been exported from Trovancore, India.

In the United States, occurrences of monazite are known in many other States than the Carolinas, but it is probable that the deposits in Idaho and the Carolinas alone are of importance commercially.

Brazil has furnished the bulk of monazite for commercial use. Little has been mined elsewhere since the enormous price cut in the earlier part of 1906, as the workings in the Carolinas have been gradually abandoned. For some years past Brazil has furnished all of the monazite for the gas-mantle industry for both Europe and the United States.

HISTORY OF PRODUCTION OF MONAZITE.

Although generally known to interested persons, a short history of the development of production and final overproduction of this once rare mineral may be warranted.

The first monazite used in Europe for chemical purposes was brought at great expense from Sweden and Norway.

About 27 years ago John Gordon, an American, found monazite on the coast of Brazil, in the State of Bahia, and brought the mineral in large quantities to Hamburg. The supply was sufficient to furnish the thorium industry of the entire world with monazite at a comparatively low price. Mr. Gordon obtained a monopoly of the Bahian monazite sands.

At that time the manufacture of thorium nitrate in Europe as a specialty was confined to a few large chemical firms in Germany and to the Welsbach Co. in Vienna. These were the only firms that provided the European market with thorium nitrate. They also sent large quantities of the nitrate to the United States. The American Welsbach Co. early manufactured thorium nitrate from sands mined in the Carolinas, a protective duty of 6 cents per pound making this possible, as the mining of monazite in this country is more expensive than in Brazil.

FIRST GERMAN THORIUM CONVENTION.

Late in 1902 Mr. Gordon entered into an agreement with the four largest German manufacturers and with the Austrian manufacturer by which he agreed to furnish monazite at a price of $150 per metric ton and a percentage of the profits from the manufactured nitrates. With this agreement a close combination was formed which prevented other thorium manufacturers from acquiring any of the mineral

mined by Mr. Gordon. The combination was known as the German Thorium Convention, which, after the conclusion of the agreement with Mr. Gordon, immediately raised the price of thorium nitrate 100 per cent.

Mr. Gordon's supply came from the coast lands of Bahia, near Prado, Brazil, and he exported the sands for a long period without interference. Finally the Brazilian Government became acquainted with the value of the resources and found an old law according to which all of the Brazilian coast lands along the sea and navigable rivers belong exclusively to the Federal Government for defensive purposes. The Government concluded, therefore, that no private individual or State government had the right to mine, sell, lease, or remove any of this property without the consent of Federal authority. In 1903 the Government of Brazil advertised that coast lands in the State of Espirito Santo would be leased to the highest bidder for the exploitation of the sands lying within its territory.

A business man living in Rio de Janeiro made a contract with the Government, but for some reason allowed it to lapse. Finally an engineer obtained the contract for the firm of A. C. de Freitas & Co., of Hamburg, Germany. By the contract the firm mentioned agreed to pay to the Brazilian Government a rental of 50 per cent of the selling price of monazite sand and to export at least 1,200 tons annually during the life of the contract.

SECOND GERMAN THORIUM CONVENTION.

To avoid interference, the German Thorium Convention arranged, later on, that half of its supply should be furnished by Mr. Gordon and half by the De Freitas Company; and a new convention was formed by the four German chemical manufacturers with Mr. Gordon and the De Freitas Company by which the latter two were to supply the monazite to the four German manufacturers only and were to receive therefor $150 per ton of monazite and a percentage of the profits from the sale of the nitrates.

As a result of the convention other firms in various countries, which had in the meantime begun to manufacture thorium nitrate, were without a supply of raw material and had to depend upon the ashes of spent mantles. Consequently, they made every effort to find and develop new deposits of monazite in Brazil, the Carolinas, and elsewhere. The whole world was searched for rare-earth minerals by their engineers, with the interest and assistance of many governments. The high price for thorium nitrate made it possible to mine monazite in the Carolinas and export it to Germany; thus one German manufacturer—an outsider—received his supply from North and South Carolina. Later, American firms independent of the Welsbach com-

panies began to buy monazite in the Carolinas, and by the competition created for a brief period caused the price for lands and monazite sand to rise to a point highly profitable to the farmers and landowners of the Carolinas.

CAUSES OF REDUCED PRICE OF THORIUM.

On account of overproduction in thorium, the price for thorium nitrate was suddenly dropped 50 per cent by the convention in the year 1906. The mining of monazite consequently decreased in all localities where the cost of the mining was high, as, for instance, in the Carolinas.

Since 1906 other difficulties have arisen between the Vienna and English Welsbach companies and the German Thorium Convention; and in 1910 the price was further lowered to a point that made the mining of monazite absolutely unprofitable in the Carolinas, and also in the interior of Brazil. The market was flooded with monazite until the outbreak of the European war.

The German Incandescent Gas Light Co. of Berlin has succeeded during the past few years in controlling the largest manufacturers of thorium nitrate in Europe with the exception of those in France. The German concern controls now both the English and Austrian Welsbach companies, and consequently their thorium nitrate plant in Austria. This combination is the strongest competitor of the so-called Thorium Convention, and the latter has lost much of its power.

CONSUMPTION OF MONAZITE.

The world's consumption of monazite is now about 3,000 tons per annum. The annual world consumption of incandescent gas mantles is estimated at three hundred million. The United States alone, in spite of the development and use of the electric metal-filament lamps, has consumed in the past few years some eighty million incandescent gas mantles as against forty million total before the year 1904.

In the manufacture of such gas mantles about 0.5 gram of ThO_2, equal to 1 gram of thorium nitrate, is used per mantle; hence, the world consumption of thorium nitrate is 300,000 kilos, equal to 150,000 kilos of ThO_2 per annum. If monazite is considered to contain 5 per cent ThO_2, with a 90 per cent recovery in the manufacture, 1,000 kilos (1 metric ton) of monazite will yield 90 kilos of thorium nitrate. The gas mantles are made of 99 per cent thorium and 1 per cent cerium.

Perhaps the best work in regard to the manufacture of thorium nitrate and incandescent gas mantles has been written by Böhm.[a]

[a] Böhm, Richard, Das Gasgluehlicht, Die Fabrikation der Gluehkoerper fuer Gasgluehlicht, Leipsic 1905; Die Thorium Industrie: Chem. Ind., vol. 9, 1906, vol. 29, pp. 450–488.

PROSPECTING FOR MONAZITE DEPOSITS.

Prospecting for monazite is similar to a search for gold. The mining pan of the batĕa is the most convenient apparatus in which to wash the gravels of the streams and separate the heavier sands, from among which monazite can be easily detected by its peculiar luster and color. Sounding rods should be employed if quick estimates are desirable and if the thickness and composition of the overlying burden in the bottom lands must be established. The concentrated material of the pannings is dried and sent to the chemical laboratory for determination of the content of thoria and other rare earths.

USE OF SPECTROSCOPE.

It probably is not widely known that the presence of some of the rare earths in monazite can be easily detected by the aid of a spectroscope, a pocket or hand spectroscope being sufficient. Peculiar as it may seem, the presence of rare earths in the monazite samples as taken from the pan can be at once determined by this method. Determination is best accomplished by spreading some of the concentrated sand on a piece of paper or cloth and holding the spectroscope over the sand at a convenient angle, the natural light falling directly on the sand. A fairly broad dark line will appear between the red and the yellow of the spectrum, and another but narrower line will be seen in the green. These dark absorption bands seem to be due principally to the presence of the rare-earth oxides of neodymium, praseodymium, and erbium contained in the mineral. Such spectrum tests for monazite can be safely relied upon when observed by the trained eye. The entire spectrum used is divided into a scale of 63 mm., the first and broader dark line becoming visible between the 13 and 15 mm. lines. The narrow dark line appears between 21 and 22 mm. of the scale.

The spectrum method of testing in the field is most helpful in faraway places where a laboratory is not available.

MONAZITE DEPOSITS IN NORTH AND SOUTH CAROLINA.

The monazite deposits in the Carolinas cover an area of several hundred square miles east of the Blue Ridge Mountains and extend in a southwest direction. In North Carolina the counties of Cleveland, Burke, Alexander, Rutherford, and Lincoln furnish the richest deposits. In South Carolina the only deposits of value are in the counties of Cherokee and Greenville.

Practically all of the monazite mined in the Carolinas is derived from the gravels in the streams and bottom lands, the miner usually following the old courses of the streams and creeks in the bottoms. The gravels are of greatly varying thickness throughout, and it is, therefore, difficult to arrive at a true estimate for an average value.

From experience, however, it can be estimated that an average thickness of the monazite-bearing gravels is between 1½ and 2½ feet. There are deposits with a thickness of 3 feet and more, but they are of rare occurrence. The top soil in the bottom lands varies on an average from 3 to 6 feet, and on the outer seams of the bottom toward the hillsides frequently increases to a thickness of 7 feet or more. The top soil is barren and consists usually of sandy soil interlined with clays, or is of clayey matter throughout. Hydraulic methods have been tried on some of the richer soil deposits, but without much success.

NORTH CAROLINA.

In North Carolina deposits of monazite sand are found in Burke County in the Brindletown district. Here monazite is obtained from the hydraulic washings of the gold placers. The content of monazite in the concentrated black sands, however, is small compared with that of the sluicing concentrates of other sections. The monazite in this section after being purified seldom shows a higher content than 3.5 to 3.75 per cent ThO_2. There is considerable magnetite in these sands, and the bulk of the concentrates consists of ilmenite (titaniferous iron).

McDowell County has a number of deposits in the vicinity of Muddy Creek. The occurrence of monazite here is closely similar to that of Brindletown, but perhaps contains less gold in the sand.

In Rutherford County, within a few miles of Rutherfordton, there are a number of deposits that have been profitably worked for some time for both gold and monazite. The gold has usually been extracted by the miner and the residues further concentrated and shipped for their content of monazite. This district is especially interesting on account of the large area of the wide bottom lands where the gravel bearing monazite and gold is found to a greater extent than in most other sections. The percentage of monazite in the gravel, however, is not large, and these lands have been worked profitably only on account of their gold content, the monazite being obtained as a by-product.

Much activity was shown years ago in the vicinity of Ellenboro, extending to Oak Spring and Sandy Run Creek and up as far as Duncan, which is about 18 miles from Ellenboro. The deposits in this region are more or less alike and the monazite obtained is of good grade and can still furnish considerable quantities of concentrates. Near Ellenboro is a hillside deposit in which monazite is found in a comparatively pure state in the sand of the hillside as well as in the gravels of the bottom lands.

Cleveland County has a considerable area of monazite-bearing gravels which extends between Shelby and Mooresboro via Fallston to a place called Zite near Carpenters Knob, a well-known peak in that section. The deposits around Fallston and in the entire Carpenters Knob region are of great importance and have furnished monazite

concentrates of especially high thorium content. The rough concentrates obtained from many of the streams in that region contain less black sand and garnets than those in most other sections.

There are also fair deposits in Lincoln County about 15 miles northwest of Lincolnton. These deposits can also be reached from Shelby, N. C.

Alexander County has furnished some monazite concentrates, and there is no doubt but that other deposits can be found in that county.

There has been in former years considerable activity also near Hildebran, Burke County, where fair deposits of considerable extent have been found.

SOUTH CAROLINA.

Nearly all the monazite-bearing gravel in South Carolina is found north of Gaffney, Cherokee County, and Cowpens, Spartanburg County, and in the vicinity of Greenville, Greenville County, south of the Southern Railway.

There is a considerable area of monazite found in the gravels of the creeks and bottoms in all of these sections, and although there have been obtained considerable quantities of monazite concentrates containing 30 to 40 per cent of monazite, the bulk of the crude concentrates coming from these South Carolina sections have been of the "black-sand" variety containing considerable ilmenite.

Many of these deposits in both North and South Carolina have been described by others, and the reader is referred to the bibliography at the end of this report.

DEPOSITS IN IDAHO AND COLORADO.

IDAHO.

The Idaho monazite deposits and the treatment of the gold-monazite-bearing sands in that State have been well described by Sterrett,[a] also by Schrader,[b] and the concentration methods for the monazite sand used in Idaho are mentioned in the report of the Idaho inspector of mines for 1910.

The monazite deposits near Centerville and Idaho City, Idaho, seem to be of especial importance. There is no doubt but that considerable monazite will be found in many places in the State and all the gravels of the deposits contain a considerable amount of gold which makes possible the working of such deposits for both gold and monazite. The gravel beds are considerably thicker than those in the Carolinas, and much monazite should be obtained from the tailings from the old gold washings. It must be remembered, however, that the wages paid to the miners in Idaho are considerably higher than those paid in the Carolinas.

[a] Sterrett, D. B., Monazite in Idaho: U. S. Geol. Survey Mineral Resources, 1909, pp. 898–903, 1910.
[b] Schrader, F. C., An occurrence of monazite in northern Idaho: U. S. Geol. Survey Bull. 430, 1910, p. 184.

COLORADO.

Monazite has been found in the State of Colorado some 20 miles south of Denver in the Newlands Gulch district, where the monazite occurs in some of the gravels, which carry also considerable gold. Monazite is also reported in the Platte Canyon.

DEPOSITS IN BRAZIL.

There are three kinds of deposits of monazitic sands found in Brazil, as follows:

1. Deposits within the marinhas (Government lands).
2. Deposits lying behind the marinhas that are private State possessions or belong to private parties.
3. Inland deposits.

The marinhas extend from points in the State of Rio de Janeiro north through the State of Espirito Santo into the State of Bahia.

The bulk of the monazite is derived from these coast sands in the States of Espirito Santo and Bahia. The monazite sand at some places could in former years be taken off the beach by skimming the surface after each tide, and was pure enough to be shipped in the crude state. In later years, however, the material has been of considerably lower grade, so that oscillating tables have been employed, and some of the sands have been washed in sluice boxes wherever enough fresh water was obtainable. The sluice boxes used are larger and of a different construction than in the Carolinas, and no perforated plate is necessary, as there is no coarse gravel in the beach sands. Electromagnetic separators have also been used direct. These coast lands, called "marinhas," are the property of the Federal Government for 33 meters inland, measured from the point where the sea waters wash the beach at mean high tide. This method of marking property is uncertain, and has, of course, given rise to disputes when boundaries are established.

At a few places along the coast are strips of monazite-bearing sands, lying directly behind or not far from the so-called marinhas, and some of these could be worked profitably were it not for the difficulties of proving to the Federal Government that these sands were not taken from the near-by marinhas. One French concern is exploiting such lands near Itabapoana, in the State of Rio de Janeiro, and has exported several hundred tons of the mineral annually for some years. There are several other deposits that could be worked, situated between Gargahu and Itabapoana; but, owing to political influences, no other concerns have thus far been able to obtain concessions.

In the interior of Brazil, monazite occurs in many places, but a fuller description of the localities and deposits will not be given here.

The deposits of monazite in the interior of Brazil are of a formation similar to those in the Carolinas, the small streams and bottom lands

containing the only deposits of sands possessing commercial importance.

The contents of monazite in the gravels of the streams and bottom lands averages about 0.25 to 0.3 per cent, a proportion about the same as that in the monazite in the Carolinas. There are richer deposits, however, in several sections.

Along the banks of larger rivers, as, for instance, the Parahyba, great quantities of black sands with traces of monazite are found. Near Sapucaia, opposite Benjamin Constant Station on the Central Railway, such deposits have been worked by a French concern. They finally had to stop work at this point and abandon also their openings in the mountainous part of this region.

Many of the inland deposits can not be exploited on account of the expense of transportation of the product, the deposits being situated many miles from the railroad and the roads and trails being in such condition that it is often difficult to travel over them even with the mule caraven (troupa). The soft clays in the thickets of the jungle-like forests and the crossing of swamps make travel in many cases almost impossible, especially with a heavy burden laden on the mule's back. The rivers in most sections are not yet navigable. Frequent floods, caused by heavy tropical rains, and the lack of proper labor make difficult continuous operation in the interior of Brazil.

At the present prices of thorium nitrate such lands in the interior can not be profitably exploited by any known method. When once the large deposits along the coast are exhausted, however, and the price for thorium rises, or if some other uses for the mineral and its rare-earth contents are discovered, then these deposits may become available.

MINING OF MONAZITE IN THE CAROLINAS.

Most of the mining for monazite in the Carolinas is carried out in a primitive way, similar to the old methods of gold mining. The gravel is washed in sluice boxes without riffles, the sands being stirred with a square shovel, with an upward movement toward the head of the sluice box, the sands of higher specific gravity being thus concentrated, whereas the lighter clay and some of the quartz sand are washed away. The gravel dug from the pit is thrown on a perforated plate, which is fastened over the head of the sluice box. The larger stones are removed from the plate. A stream of water (about 18 to 20 gallons per minute) is fed through a spout to the gravel on the screen, and the sand is washed through the holes, about one-eighth of an inch in diameter, in the plate into the head of the box. Usually two men are employed to each sluice box, one digging and lifting the gravel out of the pit to the screen and the other concentrating the sand by stirring it in the box with the motion described above. With

this method much of the finer sand is lost, as the grains of sand vary greatly in size, and the finer, heavier grains of monazite are carried away by mechanical action with the lighter and coarser quartz. If the sands are properly sized before being washed, a much better result can be obtained, and practically all of the monazite contained in the gravel or sand can thus be saved.

The sluice boxes are of such construction that easy transportation is possible, a desirable feature, because, as the gravel is worked out in one pit in one or two days' time, the boxes then have to be moved higher up the stream or bottom. It has been found more practical and cheaper to remove the box to the deposit than to bring the gravel to the box. The sluice box is usually brought over the pit, which has been worked out previous to the removal of the box, thereby furnishing, to some extent, a dumping place for the tailings that flow off the end of the sluice box. However, as the amount of tailings washed out during one day is large, the so-called "tail-raise" must be cleaned out with the shovel several times during the day, the tailings so removed being thrown to one side of the bank of the tail-raise. This is necessary in most instances, as the lands slope only slightly, and in some sections the bottoms and stream beds are almost level.

After the sands have been concentrated in the sluice box, the concentrates are often rewashed by an experienced hand and a further amount of useless material removed. The concentrates are then dried in the sun or in a form of drier—usually made of a piece of sheet iron with turned-up edges—a wood fire being built underneath.

Many of the Carolina mines could not have been exploited had it not been for the fact that the people worked out the mineral on their own account from small deposits during times when no farm work could be done. They seldom figured their time of work, mined out what they could, and brought it to the separating plants, where they were paid in cash at the rate of about 8 cents per pound of pure monazite (machine-cleaned sand). Others were employed by some of the corporations at about 80 cents to $1.25 per day at the richer mines. It was not long, however, before new dealers arrived in the Carolinas, greatly inspired by the high prices which were then paid for the nitrate, who, knowing little of the trade, and with only crude means of judging the content of monazite in the washed concentrates, paid 12, 15, and often as high as 35 cents per pound, based on concentrates containing 92 per cent monazite. This development caused unhealthy competition, which proved fatal to the farmers and small operators, as they went to large expense to produce large quantities of the sand, which they then held for higher prices, but could not sell at all when finally the market for thorium nitrate broke. To-day there is no mining of monazite in the Carolinas.

MILLING METHODS IN THE CAROLINAS.

The deposits are too scattered and are not extensive enough to make practical or profitable the use of sliming and oscillating tables. Other concentrating apparatus of special design can be utilized, and with proper sizing of the material excellent results can be obtained with such machines and methods, as has often been demonstrated by practical tests.

The concentrates produced in the sluice boxes contain 20 to 60 per cent of monazite. An average of about 35 per cent can be considered a conservative estimate as a result of practical experience. The concentrates have to be further refined, and are best treated by electromagnetic separators, of which the Wetherill-Rowand type has proved to be the most useful to the industry. The testing laboratories of Krupp now use a new type of electromagnetic separator of the Ullrich type, which treats the material either "wet" or dry. It is reported to have a capacity of about 2 tons of material per hour, which is considerably larger than that of any other type of magnetic separator heretofore known. The Daggett separator has also been used successfully for this kind of concentration.

ELECTROMAGNETIC EQUIPMENT USED.

In the separation of monazite from other minerals and its gangue materials, electromagnetic methods[a] were found to be most efficient. Weakly magnetic bodies can be separated from each other by employing highly concentrated magnetic fields. Such separation is made possible on account of the difference in the magnetic permeability of different material. However, the magnetic permeability as a physical property can be fixed only for absolutely pure material, entirely free from any admixtures, as such admixtures of foreign matter influence considerably the magnetic relativity of the material to be treated, and it therefore can not be applied as a theory in the treatment of most minerals, which always carry a certain amount of impurities. And furthermore, it is impossible to bring different minerals, by known methods of crushing, grinding, etc., to a uniform size and shape of particles, as further factors, such as amount tested and whether the charge is packed tight or loose, affect the results, and not even comparatively correct results can be obtained. Only practical tests, therefore, will satisfactorily determine the best results for ores and minerals, as on most of such electromagnetic separators the magnetic power can be controlled to the finest points by means of a rheostat. The intensity of the magnetic field must be adjusted for each specific separation of minerals.

The large type of Wetherill separator has been used in the United States and in Brazil for the concentration of monazite. The separator

[a] See Gunther, C. G., Electromagnetic Ore Separation, 1909. See also "Bibliography on magnetic concentration" in Richards, R. H., Ore dressing, 1909, vol. 2, pp. 832–837.

has two magnets of different sizes, one being nearly twice the size of the other. Each of these magnets has two pairs of poles, forming four magnetic fields and permitting a separation of two products with each magnet. (See fig. 1, p. 29.) The magnets are best adjusted so that the first pole of the first magnet removes from the sand the highly magnetic material, as, for instance, the magnetite and ilmenite; the second pole of the first magnet extracts the garnets and also the finer grains of ilmenite; the third magnet (being the first pole of the second magnet) removes all of the coarser grains of monazite; and the last pole extracts the finer grains of monazite. At the end turn of the 18-inch rubber belt of the machine the residues are then dropped into a receptacle. This is best arranged in such manner that the residues are dropped from the funnel of the receptacle into the feed box of a small oscillating table, or other suitable means for the wet concentration of the gold and zircon, which are often present in small quantities. Some fine monazite escaping with the nonmagnetic material may also be recovered.

BY-PRODUCT SEPARATION.

Sometimes the by-products are found to be valuable enough for market, and it is then of advantage to make a still finer separation, which can be accomplished by employing a type of separator with three magnets—giving six magnetic fields—of three different sizes and strengths, the last magnet being the largest and strongest. In this way the poles can be adjusted so that each magnetic field attracts and removes practically the entire amount of one certain kind of mineral contained in the sands, thereby giving six distinct products, besides all of the nonmagnetic products, which are separated at the end of the magnetic operation by running the residues over an oscillating table.

COST OF MINING AND MILLING.

The deposits of monazite sands in the Carolinas are, as has been previously stated, patchy, and not one single deposit is known to be large enough to justify the erection of a large washing and concentrating plant at the mine itself. The magnetic separators are best placed at a point on a railroad, and as nearly as possible in a district central to many deposits.

The percentage of monazite in the gravel averages 0.25 per cent. It will thus be seen that enormous quantities of crude material have to be handled in order to obtain a ton of marketable material—about 400 tons of gravel furnishes 1 ton of monazite. In addition, the quantities of barren overburden which must be removed have to be added. The overburden often averages more than double the amount of gravel to be moved. No monazite in the Carolinas can be mined by present methods for less than 6 to 8 cents per pound of

monazite contained in the concentrated material as taken out of the sluice box. This means that to the cost of the mining must be added the cost of further concentration, sacking, interest on investment, amortization on plant, management, freight, cartage, etc.

One man can dig and remove in nine hours (this being the usual working shift in the Carolinas) about 9 cubic yards of material, including top soil, barren sand and clay, and monazite-bearing gravel.

The wages paid are $1 to $1.25 a day. Therefore if we take for a rough calculation an area of 3 square yards of ground and a depth of soil and gravel of 9 feet, equal to 27 cubic yards, or about 80,000 pounds in weight, the cost would be as follows:

For digging and removing of barren material and dump, and digging and removing to sluice box of the monazite-bearing gravel, 3 men at $1.25, 1 day each, or $3.75; for rough washing of 9 cubic yards of gravel in sluice box, 1 man 1 day, $1.25; final cleaning up in special sluice box of rough concentrates, $0.50—a total of $5.25.

As the content of monazite in gravel is 0.25 per cent, or about 68 pounds of pure monazite in washed concentrates, the cost is about $7\frac{3}{4}$ cents per pound of monazite contained in the washed concentrates.

The cost of transportation to the magnetic separator varies according to the distance over which the material has to be hauled, and averages about $4 per ton of monazite in concentrates, making a total cost of $159 per ton of monazite in concentrates. To this has to be added the cost of drying of the crude concentrates, and of electromagnetic separation. When the plant is running to its full capacity (9-hour shift), turning out about 3 tons of pure monazite per shift, $10 for treatment, depreciation, separation, and repairs can safely be added to the above amount per ton of monazite. The entire cost of 1 ton of machine-separated monazite, containing 92 to 95 per cent monazite and about $4\frac{1}{2}$ per cent ThO_2 is, therefore, $169 at the concentrating plant. To this has to be added the cost of management, commissions, tolls, if any, loading on cars, and freight to chemical plant or port.

COMMENTS ON ELECTROMAGNETIC PROCESS.

In concentrating monazite sands by the electromagnetic process, it is essential that great care be taken throughout the entire operation that the strength of the current is the same at all times, as the slightest variation will cause imperfect separation. An impure product and much loss of monazite will result unless this precaution is observed, as the monazite will be taken up by the wrong poles. This contingency is more fully illustrated below:

If the strength of current be too great, some of the monazite will be mixed with the valueless ilmenite or garnets; or, if the amperage be too low, ilmenite or garnets will be carried over to the next following pole, and will then become mixed with the monazite, and, at the same

time, too many of the finer grains of monazite will escape in the tailings. The distance between pole magnets must be carefully adjusted, and the number of amperes for each magnet regulated by rheostats for each kind of sand, for every section of the country, or even when from the same section different percentages of monazite and impurities are present.[a]

It may be stated that a better result is obtained when the sands are slightly roasted before magnetic separation than if they are simply sun-dried or air-dried. The difference is due to the fact that roasting renders the material more magnetic. It has accordingly been found that the proper adjustment of the amperage for magnetic separation is quite different for sands that have been sun-dried than for those dried over the fire.

Other electromagnetic separators have been used, operating on similar principles, but did not give as high concentrates in one operation as the Wetherill type, although, perhaps, the new Krupp separator may do so. However, some other concentrators have been used with fair results.

By-products usually found in the residues that can be separated by employing an oscillating table are zircon, rutile, gold, and sometimes platinum. Some of the platinum is slightly magnetic, and may be lost during this process of separation.

ESTIMATED MONAZITE RESOURCES.

It is difficult to give even a rough estimate of the quantities of monazite obtainable in the various countries where it occurs. From close calculations, however, it is estimated that the lands in the marinhas along the sea coast of Brazil may yield from 15,000 to 20,000 tons of pure monazite. This does not include coast lands where the deposits have been formed in comparatively short time.

In the interior of Brazil the writer knows of about 18,000,000 tons of monazite-bearing gravel deposits which should yield monazite containing 4½ per cent of thorium oxide; and it can be estimated that these gravels contain 45,000 to 60,000 tons of monazite. No doubt there will be found many other deposits of greater or less extent in the interior of Brazil, but no single deposit in the interior, so far as known, would warrant the erection of a large plant. In sections where several large deposits are found together or near each other a washing and concentrating plant might be profitably established, provided that the price for the monazite obtained were higher than at present (May, 1915), and especially if transportation facilities from the interior to the coast became better.

The amount of purified monazite available in the Carolinas may be conservatively estimated at about 15,000 to 20,000 tons (4½ per cent ThO_2).

[a] See table on page 28.

With better methods of mining and refining the monazite, perhaps those deposits could be profitably exploited at the present prices for monazite and thorium nitrate, especially if the mining of monazite were carried on in connection with the manufacture of thorium nitrate and mesothorium.

It is known that attempts have been made to extract the monazite from the native rock, but this operation with even the richest rock known—0.1 to 0.2 per cent of monazite—has proved to be too expensive, and such endeavors have been given up as hopeless.

DUTY ON MONAZITE EXPORTED FROM UNITED STATES AND BRAZIL.

UNITED STATES.

There is no duty on monozite exported from the United States.

BRAZIL.

The duties on monazite exported from Brazil vary greatly, and are as follows:

BRAZILIAN EXPORT DUTIES.

Federal Government.—Duty on monazite from the marinhas—situated along the entire coast and navigable rivers of Brazil—is charged at the rate of 50 per cent ad valorem, and is fixed at £30, or about $150, per ton. Individual States have fixed duties, as follows:

Rio de Janeiro.—65$000 per metric ton (approximately $21).

Espirito Santo.—80 per cent of selling value, established to be £25 per ton. This duty is varying and is subject to reduction when applied for.

Minas Geraes.—12 per cent ad valorem, fixed at £25 per ton and 25 per cent ad valorem, fixed at £25 per ton, plus £2 specific duty.

IMPORT DUTIES ON MONAZITE.

The duty on monazite imported into the United States has been 6 cents per pound, but was reduced to 4 cents in 1910, and is now 25 per cent ad valorem.

The import duty on mantle ashes is $10 ad valorem.

The import duty on nitrates has been 25 per cent ad valorem.

EXAMINATION AND VALUATION OF MONAZITE DEPOSITS.

The following features should be ascertained in the investigation of monazite deposits for exploitation:

1. Extent and depth of the monazite-bearing alluvial deposits, sands, and gravels in river beds and bottoms.

2. Amount and character of barren overburden overlying the gravel or sand deposit.

3. The percentage of monazite contained in the raw material to be treated.

4. Percentage of thorium oxide contained in the monazite.
5. Transportation facilities and cost of transportation.
6. Water conditions—rain-fall throughout the year and water supply for concentrating purposes and for the boiler.
7. Timber obtainable on or near property for building use, fuel, etc.
8. Depth and character of bedrock.
9. Occurrence and character of clays.
10. Power available.
11. Labor, also conditions for housing.
12. Mining laws.
13. Cost of supplies.
14. Import and export duties.
15. Best-suited methods for exploitation (concentration, etc.)
16. Quantities and value of by-products and methods of obtaining same.
17. Dumping ground.
18. Inclination of surface of property.

These points having been thoroughly determined, and also whether the existent volume of material, together with other conditions, will warrant exploitation and the erection of a plant, it should be concluded from the topographic features which methods of exploitation of the material will be most suitable.

In determining the average extent and depth of such alluvial deposits great care must be taken to ascertain the situation of the old channels of the streams, as many of the deposits in bottom lands are irregular, so that a true estimate of the amount of gravel or sand contained can be given only after thorough testing by way of soundings, and especially by opening test pits at short distances from each other. As the percentage of the mineral contained in the gravels is small and the thickness of the deposit is usually slight, it will be realized that an enormous area of gravel and sand deposit must be within easy reach to insure profitable exploitation. The relation of volume to richness is therefore a most important consideration.

Transportation is a feature that has to be well considered.

In sections in the Carolinas quickly rising streams and sudden torrents have destroyed dams and carried away sluice boxes, implements, and other materials obtained by hard labor. Uncovered deposits have been covered up again with the sands and mud brought from the mountains during such torrents. Rich deposits have also been purchased during favorable seasons, which could ordinarily be worked during short periods only, on account of lack of water or, in winter, hard frozen gravel, the thawing of which was too expensive. Had the conditions been properly studied, much loss might have been avoided.

Careful forethought regarding a dumping ground should be made in all developments, for large quantities of bowlders, clay, and tailings are produced. The deposits may become choked because the refuse material is dumped in an undesirable place, causing further work to be abandoned, as the removal of dump material is costly.

Clays give great trouble when present as an overburden or, as is of frequent occurrence in the Carolinas, when mixed in large quantities with the gravel. The removal of the clayey overburden is much more expensive than removal of sandy materials, and when the clay is mixed with gravel washing consumes more time and large volumes of water.

When clay is mixed with gravel, particular care must be used in removing it, as much monazite may adhere to it. The clays seldom contain any of the mineral, but the mineral becomes embedded in the outer parts of the clay while lying in the alluvium. The practice of cutting up the clay is useless and wasteful, although this method has been followed by some of the operators. It is sufficient to wash the surface of such clays carefully and then remove them to the dump.

ATTEMPTS TO USE BY-PRODUCTS.

Attempts have been made to utilize by-products from Carolina monazite. Twenty tons or more of ilmenite has been shipped to Europe, but could not bear transportation costs. Garnets derived from the separators have been widely offered, but have been found to be of no value as abrasives, the grains being rounded off by the constant friction while rolling along with other sands in the stream beds. The larger particles of garnets obtained by classification, which could have been crushed, and thereby had their sharp edges preserved, have been obtained in small quantities only from the monazite sands.

In some sections gold is found in the concentrates. Although the amount so obtained has been small, it has paid to put aside the residues after treatment by electromagnetic methods, and then, when sufficient quantities have been collected, to concentrate them on an oscillating table or by some other suitable process. Although the proportion of gold contained in such sands is not great, it has been known to have a value of about $200 per 30 tons of monazite, which is equal to about 1½ cents per ton of gravel. This could be considered almost clear profit, as the extraction of the gold from the residues is inexpensive. Monazite sands purchased from gold-mining sections, which have been treated for gold by the miners, have, after the separation of the monazite, yielded a further small amount of the precious metal.

In many sections "black sands" accompany monazite in large quantities.

In this paper methods of treatment in actual use have been described. It is, however, more than probable that small dredges would prove useful in the mining of monazite as they have in the western field for gold.

METHOD FOR THE DETERMINATION OF THORIUM IN MONAZITE.

Many methods for determining thorium in monazite have been described. Only the following well-known method is alone given here.[a]

About 1 gram of the monazite is ground to an impalpable powder, weighed into a platinum vessel, covered with 15 to 20 c.c. of concentrated sulphuric acid, and evaporated until fumes are no longer driven off. More sulphuric acid is added and heated as before. The operation is repeated several times until the conversion of the phosphates into sulphates is complete. The mass resulting is added in small quantities to about 700 c.c. of water at 0° C., with constant stirring, care being used not to allow the temperature to rise higher than 2° C. The solution is allowed to stand 10 to 12 hours, when it is filtered and washed. The filtrate is then nearly neutralized with dilute ammonia, 50 c.c. of a cold saturated solution of oxalic acid is added with constant stirring, and the solution is allowed to stand for 12 hours. The solution is then filtered and the precipitate washed well with water. The precipitated oxalates are then washed into a beaker and treated with a strong solution of caustic potash, heated to boiling, diluted, and filtered.

The hydroxides are washed thoroughly with water and dissolved off the filter with hot dilute hydrochloric acid (1–1). The solution is evaporated to dryness to free it from acid, taken up with 75 to 100 c.c. of water, 15 c.c. of a saturated solution of sodium thiosulphate is added, and the solution is heated to boiling. It is then filtered and the precipitate and the filter set aside for subsequent filtration. An excess of ammonia is added to the filtrate, the precipitate is filtered off, washed, dissolved in hydrochloric acid, and evaporated to dryness, the residue being taken up in water and reprecipitated with thiosulphate as before. The solution is filtered through the filter paper carrying the first precipitate, and the filtrate is treated as before. The precipitations are continued as long as the precipitate forms with the thiosulphate, three precipitations usually being sufficient to completely extract the thorium. The combined precipitates of thorium-thiosulphate are washed completely, dried, and ignited. The ignited mass is fused for some time with potassium bisulphate, taken up in water, and a few drops of hydrochloric acid added, and precipitated with oxalic acid. The oxalates are converted

[a] See Metzger, F. J., A new separation of thorium from cerium, lanthanum, and didymium, and its application to the analysis of monazite, Jour. Am. Chem. Soc., vol. 24, 1902, p. 901; see also Levy, S. I., The rare earths, London, 1915, pp. 285–290.

into the hydroxides, dissolved in hydrochloric acid, evaporated to dryness, taken up in water, and reprecipitated with sodium thiosulphate, filtered, washed, dried, ignited, and weighed as ThO_2.

TREATMENT OF MONAZITE FOR THE EXTRACTION OF THORIUM.

Soddy [a] gives in a short form the technical treatment of the monazite sand as it is carried on to-day in the industry.

In the first stage of the technical treatment of the monazite sand, which is ground up very fine, it is heated with twice its weight of sulphuric acid. The further procedure in the treatment is described by Soddy [b] as follows:

> The cold mass is dissolved in water and left to settle. The solution is then fractionally precipitated with magnesia, the thorium being concentrated mainly in the first fractions precipitated. The commonest and most useful reagent for precipitating the rare earths from a solution containing common earths such as alumina, iron, etc., is oxalic acid. Now thorium oxalate is of all the rare-earth oxalates the least soluble in acids, so that by working in fairly strong nitric acid solution thorium oxalate may often be precipitated and separated at least partially from the other rare earths and from calcium. The same is true of the rare-earth phosphates, that of thorium being one of the most insoluble in dilute acids. On the same principle thorium is often precipitated by weak bases, such as the substituted ammonias, for example, dimethylamine, while zirconium, etc., remain dissolved. The potassium salt of hydrazoic acid, KN_3, precipitates thorium hydroxide only from mixtures of thorium and cerium on boiling. The same separation may be effected by means of sodium thiosulphate on boiling, thorium alone being separated, as hydroxide. This ready hydrolysis of weak thorium is characteristic of the element. The oxalates of thorium and zirconium alone of the rare earths are soluble in ammonium oxalate, and on strongly acidifying the solution the former alone is reprecipitated. The solution of the oxalate of thorium and its conversion into soluble salts may be effected by means of concentrated ammonium or sodium carbonate and precipitation of the concentrated solution as thorium hydroxide with strong ammonium or sodium hydrate. Thorium is distinguished from the yttrium group of the rare earths by its power of forming a double sulphate with potassium sulphate, insoluble in excess of the latter reagent, and so may be separated from a mixture of the sulphates by saturating the solution with potassium sulphate. Alike in the old, now obsolete, as in the present, technical methods of purifying thorium, the peculiar solubility relations of thorium sulphate in water have been largely applied. The older method consisted in volatilizing the excess of sulphuric acid from the material being treated, and in dissolving the anhydrous sulphates in ice-cold water—a tedious operation—and in heating the solution till the hydrated thorium sulphate was precipitated. The latter was then dehydrated at 300° to 400° and the process repeated. In present practice the sulphuric acid is always kept in great excess in the initial treatment of the mineral, but the sulphate method may be employed at the final stage of manufacture as follows:
>
> The thorium hydroxide is dissolved in hydrochloric acid, so that the solution contains not more than 30 per cent ThO_2, and sulphuric acid is added to the extent of 0.5 per cent more than the equivalent quantity, the temperature being kept low, and in any case below 40° as a maximum. Under these conditions the hydrate $Th(SO_4)_2 8H_2O$ is precipitated, departure from the conditions causing the separation

[a] Soddy, Frederick, The chemistry of the radio elements, 1911, pp. 64–69; see also, Böhm., Richard, Die Darstellung der seltenen Erden, Leipzig, 1905, vol. 2, pp. 94–98; Levy, S. I., The rare earths, London, 1915, pp. 276–285.

[b] Soddy, Frederick, loc cit.

of the tetrahydrate, which is in every way less easily manipulated. The precipitated sulphate is reconverted into hydroxide, and the process repeated as often as necessary to remove all impurities.

Thorium forms a curious compound with acetyl acetone, $Th(C_5H_7O_2)_4$, which is soluble in chloroform and alcohol, and can be distilled in a vacuum, and so can advantageously be employed for the purification and separation of the element.

It may be mentioned that in the fusion of refractory minerals, as with sodium carbonate, the thorium, if present, is converted into the highly insoluble oxide, ThO_2, and its presence is apt to be overlooked.

Thanks largely to the thorium industry, in which a product unusually pure is essential, there exist, therefore, a great variety of exceedingly good and sharp methods for the separation and purification of thorium, and it must be understood that ionium, if present, and radio-thorium always remain unseparated from thorium in these processes as far as they have been examined.

In the manufacture of thorium nitrate from monazite a large amount of residues of the cerium group of rare earths is obtained. Monazite contains 60 to 70 per cent of the cerium group or other rare earths besides thorium, and 3,000 tons, which is the annual consumption of monazite, gives about 1,000 tons of cerium and about 1,200 tons of a mixture of the rare earths, lanthanum, neodymium, and praesodymium oxides. Considerable research work has been done in order to utilize these waste materials, and experiments have been made with almost every one of them. In order to obtain and separate the rare-earth elements, thousands of crystallizations and fractionations are necessary, although cerium itself is separated with comparative ease. The untiring work carried on in the research laboratories of the industries as well as by the scientists in both America and in Europe will, no doubt, in time be crowned with successful technical applications of the by-products.

SEPARATION OF MESOTHORIUM ON A COMMERCIAL SCALE.

Monazite sand is the main source of mesothorium and contains also uranium and, consequently, radium. Mesothorium has properties similar to radium, and the radium therefore is separated together with the mesothorium. The methods employed in the extraction of mesothorium are well known and have been described by Haitinger and Ulrich [a], and have been used in the extraction of radium.[b]

Some manufacturers of mesothorium add a small quantity of barium sulphate to the monazite sand during its treatment with sulphuric acid, whereby the mesothorium is separated with the insoluble material left after the treatment of the product with water.

The half-value period or period of half life (the time required in which one-half of any given quantity of radioactive matter disintegrates—becomes transformed—is called half-value period or period of

[a] Haitinger, Ludwig, and Ulrich, Karl, Bericht über die Bearbeitung der Pechblende Rückstände: Ber. K. Akad. Wiss., vol. 117, 1908, p. 619.

[b] Moore, R. B., and Kithil, K. L., A preliminary report on uranium, radium, and vanadium: Bull. 70, Bureau of Mines, 1914, p. 79.

half life) of mesothorium is 5.5 years, whereas that of radium is about 2,000 years.

The manufacture of mesothorium alone from monazite is not profitable, as the value of the mesothorium extracted would not pay for the cost of the monazite. As a by-product from thorium nitrate manufacture such manufacture should be of importance.

QUANTITATIVE DETERMINATION OF MESOTHORIUM.

The quantitative determination of mesothorium is carried on in the same manner as for radium.[a]

The content of mesothorium in preparations, all of which carry about 25 per cent of radium, is expressed in terms of the gamma ray activity of radium in equilibrium. For example, 5 milligrams of mesothorium on this standard indicates that the gamma ray activity of the mesothorium plus the radium contained in it one month after separation gives a gamma ray activity equal to that of 5 milligrams of pure radium bromide.

If both the radium and the mesothorium are to be determined then radium plus mesothorium is determined by means of the gamma ray method, and afterwards, by the emanation method, the radium alone is determined.

By the gamma ray method alone can be determined the ratio of radium to mesothorium by measuring the gamma rays before and after boiling the solutions. The content of mesothorium plus radium is found before the solution is boiled; after it has been boiled, the content of mesothorium alone is given, as the radium emanation is removed by boiling, and radium C_1, which emits the gamma rays, is, for all practical purposes, disintegrated after three hours' time.

In regard to the method of measuring mesothorium and radium by the gamma ray method, reference is made to the work of Ebler,[b] and of Meyer and Hess.[c]

The quantities of mesothorium that can be extracted from monazite are, of course, very small. One hundred metric tons of monazite with a content of 5 per cent ThO_2 contains approximately 4.3 tons of thorium metal. According to Rutherford,[d] one metric ton of thorium metal contains 0.42 milligram of mesothorium. We have, therefore, 0.42 milligram of mesothorium per weight of 10^{-6} grams of thorium, or 4.3 times 0.42, equals 1.8 milligrams of mesothorium by weight. The activity due to mesothorium is three times as great as

[a] Soddy, Frederick, The chemistry of the radio elements, 1911, pp. 46–49; Rutherford, E., Radioactive substances and their radiations, 1913, p. 550.

[b] Ebler, Erich, Chemiker Kalender for 1914, vol. 2, pp. 371–372.

[c] Meyer, Stefan, and Hess, V. F., Gamma Strahlenmessung von Meso-thorpräparaten: Mitt. Inst. Radiumforschung, Vienna, July 2, 1914, pp. 1443–1458.

[d] Rutherford, E., Radioactive substances and their radiations, 1913, p. 552.

that due to radium when compared weight with weight. The mesothorium obtained from one ton of monazite, therefore, would be calculated as 5.4 milligrams. Lorenzen,[a] however, states that technically 2.5 milligrams of mesothorium can be obtained from 1 metric ton of monazite, or 100 tons of monazite would yield 250 milligrams of mesothorium. It seems, therefore, that technically a recovery of about 50 per cent is made. Mesothorium is sold on the basis of its activity compared with radium bromide of highest purity (determined by the gamma ray method), and has been sold with increasing demand at $45 to $60 per milligram. The separation of mesothorium has been widely discussed in scientific and technical papers and is outlined on page 25.

The manufacture of thorium nitrate from monazite is well known and has been described extensively. This manufacture, however, is briefly described on pages 24–25. The manufacture of the thorium nitrate is so highly developed that a recovery of 90 to 95 per cent of the thorium contained in the monazite has been made by many industrial concerns.

Although in former years monazite and thorium nitrate were imported into this country, lately, since the manufacture of mesothorium from the thorium residues has been begun, Europe prefers to export the ash of the broken incandescent mantles, which are high in ThO_2, and keeps the monazite in order to obtain the mesothorium from the residues. The import duty on the ash brought into the United States is only 10 per cent ad valorem, whereas thorium nitrate pays 25 per cent duty. The thoria ash has been sold for 25 marks ($6) per kilogram in Europe.

MINERALS IN MONAZITE SANDS.

The minerals contained in monazite sands, arranged according to their specific gravity, are shown in the tabulation following:

Minerals contained in monazite sands, arranged according to specific gravity.

Mineral.	Specific gravity.	Letter showing relative quantitative occurrence.[b]	Mineral.	Specific gravity.	Letter showing relative quantitative occurrence.[b]
Quartz	2.65	*a*	Rutile	4.2 to 4.25	*h*
Feldspar	2.5 to 2.7	*c*	Zircon	4.5 to 4.7	*i*
Tourmaline	3.0 to 3.2		Ilmenite	4.5 to 5	*b*
Apatite	3.2 to 3.25	*g*	Monazite	4.8 to 5.3	*f*
Epidote	3.2 to 3.5		Magnetite	5.16 to 5.18	*d*
Olivine	3.3 to 3.6		Gold	15 to 19	*k*
Garnet	3.8 to 4.3	*e*			

[a] Private information received from Julius Lorenzen, Tegel-Berlin, on Chemical Manufacture of Mesothorium.

[b] The order varies according to localities.

The conglomerate must be freed from the larger gravels and from the clays.

Proper sizing is important before concentration; in sizing the remaining clay and mica particles should be removed by a sliming process.

Four or five sizes should be made through sieves of 20, 50, 80, and 100 mesh.

Such properly sized material when treated on the large type of Wetherill electromagnetic separator, having two magnets and 18-inch belt, gives the following results:

Results of action of Wetherill electromagnetic separator on properly sized monazite sands.

Mineral.[a]	Point in separator at which mineral separated.	Current.
Magnetite		Very weak.
Ilmenite	First pole, first magnet; distance between poles, about 8 mm.	
Hematite		
Garnet	Second pole, first magnet; distance between poles, about 3 mm.	1 to 5 amperes.
Platinum (if any)		
Epidote		
Apatite		
Olivine		
Tourmaline		
Monazite (92 to 95 per cent) and traces of zircon and rutile.	First and second pole of second magnet; distance, first pole, 6 mm.; second pole, 2 to 3 mm.	12 to 15 amperes.
Platinum, etc. (if any)		

[a] Residues off belt were quartz, feldspar, gold, zircon, rutile, etc.

Data showing fluctuation of prices for thorium nitrate for use in incandescent gas mantles.[a]

Year.	Price of thorium nitrate.	
	Europe (per kilo).	United States (per pound).[b]
	Marks.	*Dollars.*
1894	2,000	
1895, January	900	
1895, July	500	
1895, November	300	
1896, early part	150	
1896, later part	96	
1897	60	
1898	40	
1899	30	
1900	28	
1902	36	
1903	43	5.86
1904, early part	43	5.86
1904, later part	43	6.10
1905	43	6.53
1906	27	3.78
1907, early part	32	3.93
1907, later part	32	4.65
1908	32	4.70
1909	27	3.87
1910, early part	19	3.20
1910, later part	17	3.00
1911	22	3.00
1912	22	3.00
1913, early part	21	2.85
1913, later part	21	2.60
1914, early part	22	2.71
1914, later part	22	3.25

[a] Import duty on thorium nitrate brought into the United States, 25 per cent ad valorem.
[b] Data furnished by Dr. Hugo Lieber, 25 Madison Avenue, New York, N. Y.

FLOW SHEET.

A flow sheet of the separation process is shown in figure 1.

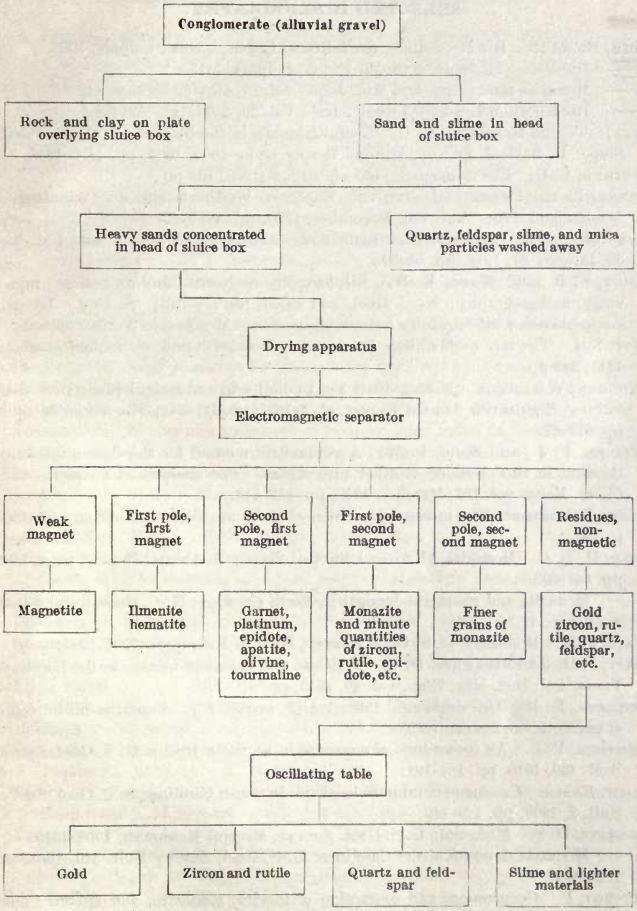
Conglomerate (alluvial gravel)
Rock and clay on plate overlying sluice box
Sand and slime in head of sluice box
Heavy sands concentrated in head of sluice box
Quartz, feldspar, slime, and mica particles washed away
Drying apparatus
Electromagnetic separator
Weak magnet
First pole, first magnet
Second pole, first magnet
First pole, second magnet
Second pole, second magnet
Residues, non-magnetic
Magnetite
Ilmenite hematite
Garnet, platinum, epidote, apatite, olivine, tourmaline
Monazite and minute quantities of zircon, rutile, epidote, etc.
Finer grains of monazite
Gold zircon, rutile, quartz, feldspar, etc.
Oscillating table
Gold
Zircon and rutile
Quartz and feldspar
Slime and lighter materials

FIGURE 1.—Flow sheet, showing steps in process of magnetic separation of monazite sands.

SELECTED BIBLIOGRAPHY.

BÖHM, RICHARD. Die Darstellung der seltenen Erden, 2 vols., Leipzig, 1905.

——— Die Verwendung der seltenen Erden, Leipzig, 1913.

——— Monazite sand: Eng. and Min. Jour., vol. 81, May 5, 1906, p. 842.

——— Die Thorium Industrie: Chem. Ind., vol. 29, 1906, pp. 450–488.

DAY, D. T., and RICHARDS, R. H. Useful minerals in the black sands of the Pacific Slope: U. S. Geol. Survey, Mineral Resources for 1905, 1906, pp. 1175–1258.

GUNTHER, C. G. Electromagnetic ore separation, 1909, 193 pp.

JOURNAL OF THE FRANKLIN INSTITUTE. Report on Welsbach light, by Committee on Science and Arts. Vol. 150, December, 1900, pp. 406–415.

JOHNSTONE, S. J. Monazite from some new localities: Jour. Soc. Chem. Ind., vol. 33, January 31, 1914, pp. 55–59.

LANEY, F. B., and WOOD, K. H. Bibliography of North Carolina geology, mineralogy, and geography: N. C. Geol. and Econ. Survey Bull. 18, 1909. Gives a comprehensive bibliography concerning monazite deposits in North Carolina.

LEVY, S. I. The rare earths, their occurrence, chemistry, and technology, London, 1915, 345 pp.

LINDGREN, WALDEMAR. Mining district of Idaho Basin and Boise Ridge: U. S. Geol. Survey, Eighteenth Annual Report, pt. 3, 1898, pp. 617–744; The monazite sands, pp. 677–679.

METZGER, F. J., and ZONS, F. W. A volumetric method for the determination of thorium in the presence of other rare earths. The analysis of monazite sand: Chem. News, vol. 107, March 7, 1913, pp. 112–113.

MINING REPORTER. The industrial position of thorium. Vol. 53, February 22, 1906, p. 190.

NITZE, H. B. C. Monazite, U. S. Geol. Survey, Sixteenth Annual Report, pt. 4, 1896, pp. 667–693.

——— Monazite and monazite deposits in North Carolina: N. C. Geol. Survey Bull. 9, 1895, p. 47.

PRATT, J. H. Monazite: U. S. Geol. Survey, Mineral Resources, 1901–1905.

PRATT, J. H., and STERRETT, D. B. Monazite and monazite mining in the Carolinas: Trans. Am. Inst. Min. Eng., vol. 40, 1910, pp. 315–340.

RICHARDS, R. H. Ore dressing. 1909, vol. 2, pp.832–837. Contains bibliography of magnetic ore concentration.

SCHRADER, F. C. An occurrence of monazite in northern Idaho: U. S. Geol. Survey Bull. 430, 1910, pp. 184–191.

SLOAN, EARLE. Catalogue of mineral localities in South Carolina: S. C. Geol. Survey Bull. 2, 1908, pp. 129–142.

STERRETT, D. B. Monazite: U. S. Geol. Survey, Mineral Resources, 1906–1910.

——— Monazite deposits of the Carolinas: U. S. Geol. Survey Bull. 340, 1908, pp. 272–285.

TRUCHOT, P. Occurrences and extraction of thorite, monazite, and zircon: Chem. News, vol. 77, pp. 134–135, 145–147, 1898.

PUBLICATIONS ON MINERAL TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines is temporarily available for free distribution. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN [illegible]. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp., 6 figs.

BULLETIN [illegible]6. The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl., 1 fig.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs.

BULLETIN 45. Sand available for filling mine workings in the northern anthracite coal basin of Pennsylvania, by N. H. Darton. 1913. 33 pp., 8 pls., 5 figs.

BULLETIN 47. Notes on mineral wastes, by C. L. Parsons. 1912. 44 pp.

BULLETIN 53. Mining and treatment of feldspar and koalin in the southern Appalachian region, by A. S. Watts. 1913. 170 pp., 16 pls., 12 figs.

BULLETIN 64. The titaniferous iron ores of the United States, their composition and economic value, by J. T. Singewald, jr., 1913. 145 pp., 16 pls., 3 figs.

BULLETIN 70. A preliminary report on uranium, radium, and vanadium, by R. B. Moore and K. L. Kithil. 1913. 101 pp., 4 pls., 2 figs.

BULLETIN 71. Fuller's earth, by C. L. Parsons. 1913. 38 pp.

BULLETIN 81. The smelting of copper ores in the electric furnace, by D. A. Lyon and R. M. Keeney. 1914. 80 pp., 6 figs.

BULLETIN 84. Metallurgical smoke, by C. H. Fulton. 1914. 94 pp., 6 pls., 15 figs.

BULLETIN 85. Analyses of mine and car samples of coal collected in the fiscal years 1911 to 1913, by A. C. Fieldner, H. I. Smith, A. H. Fay, and Samuel Sanford. 1914. 444 pp., 2 figs.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

TECHNICAL PAPER 8. Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1913. 42 pp., 12 figs.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 38. Wastes in the production and utilization of natural gas, and means for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

TECHNICAL PAPER 39. The inflammable gases in mine air, by G. A. Burrell and F. M. Seibert. 24 pp., 2 figs.

TECHNICAL PAPER 41. Mining and treatment of lead and zinc ores in the Joplin district, Missouri; a preliminary report, by C. A. Wright. 1913. 43 pp., 5 figs.

TECHNICAL PAPER 43. The influence of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 1 pl., 8 figs.

TECHNICAL PAPER 50. Metallurgical coke, by A. W. Belden. 1913. 48 pp., 1 pl., 23 figs.

TECHNICAL PAPER 60. The approximate melting points of some commercial copper alloys, by H. W. Gillett and A. B. Norton. 1913. 10 pp., 1 fig.

TECHNICAL PAPER 66. Mud-laden fluid applied to well drilling, by J. A. Pollard and A. G. Heggem. 1914. 21 pp., 12 figs.

TECHNICAL PAPER 70. Methods of oil recovery in California, by Ralph Arnold and V. R. Garfias. 1914. 57 pp., 7 figs.

TECHNICAL PAPER 76. Notes on the sampling and analysis of coal, by A. C. Fieldner. 1914. 59 pp., 6 figs.

TECHNICAL PAPER 81. The vapor pressure of arsenic trioxide, by L. H. Duschak. 1915. 22 pp., 2 figs.

TECHNICAL PAPER 88. The radium-uranium ratio in carnotites, by S. C. Lind and C. F. Whittemore. 1915. 29 pp., 1 pl., 4 figs.

TECHNICAL PAPER 89. Coal-tar products, and the possibility of their successful manufacture in the United States, by H. C. Porter, with a chapter on coal-tar products used in explosives, by C. G. Storm. 1915. 21 pp.

TECHNICAL PAPER 90. Metallurgical treatment of the low-grade and complex ores of Utah; a preliminary report, by D. A. Lyon, R. H. Bradford, S. S. Wentz, O. C. Ralston, and C. L. Larson. 1915. 40 pp.

TECHNICAL PAPER 95. Mining and milling of lead and zinc ores in the Wisconsin district, Wisconsin, by C. A. Wright. 1915. 39 pp., 2 pls., 5 figs.

TECHNICAL PAPER 99. Probable effect of the war in Europe on the ceramic industries of the United States, by A. S. Watts. 1915. 15 pp.

Date Due

DEC 2 1979
REC'D
GG NOV 30 '79

PRINTED IN U. S. A.

The RALPH D. REED LIBRARY
DEPARTMENT OF GEOLOGY
UNIVERSITY of CALIFORNIA
LOS ANGELES, CALIF.

THE LIBRARY
UNIVERSITY OF CALIFORNIA
LOS ANGELES

Gaylord
PAMPHLET BINDER
Syracuse, N. Y.
Stockton, Calif.

UCLA-Geology/Geophysics Library
TN 948 M7K6
L 006 566 638 0

UC SOUTHERN REGIONAL LIBRARY FACILITY
AA 001 274 520 4